SPECIAL REPORT 90-29

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Model Study of the Cazenovia Creek Ice Control Structure

Gordon E. Gooch and David S. Deck

August 1990

For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide*, published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

Special Report 90-29

U.S. Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

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August 1990

Prepared for
U.S. ARMY ENGINEER DISTRICT, BUFFALO

PREFACE

This report was prepared by Gordon E. Gooch, Civil Engineering Technician, Ice Engineering Research Branch, and David S. Deck, Research Hydraulic Engineer, Ice Engineering Research Branch, Experimental Engineering Division, USA Cold Regions Research and Engineering Laboratory. This study was supported by the U.S. Army Engineer District, Buffalo, under Reimbursable Order No. NCB-1A-83-87RC (Change No. 3), *Design Support of Ice Retention Structure for Cazenovia Creek, Detailed Project Report.*

The report was technically reviewed by Dr. Jean-Claude Tatinclaux and Dr. James Lever, Ice Engineering Research Branch, USACRREL.

Historical data were provided by the U.S. Army Engineer District, Buffalo, Corps of Engineers Flood Plain Information Report, 1966 (reprinted June 1971).

The authors wish to thank Dr. Tatinclaux for his help in the organization of the material presented and, in particular, for his valuable input to the section on Physical Models. Many thanks are due to Calvin Ackerman whose skillful and persistent craftsmanship in the model construction resulted in an accurate calibration and consistent test results.

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Model Study of the Cazenovia Creek Ice Control Structure

GORDON E. GOOCH AND DAVID S. DECK

INTRODUCTION

Ice-jam flooding of the business and residential communities of West Seneca and Buffalo, New York, along Cazenovia Creek generally occurs during major spring runoff events due to snowmelt and rainfall. During such events, ice jams form where the Cazenovia Creek joins with the Buffalo River because of poor ice transport, which results from a change in slope in the creek and backwater effects from Lake Erie.

Between 1960 and 1965 the City of Buffalo undertook a number of efforts to reduce or eliminate ice-jam flooding along Cazenovia Creek. These efforts fell into three categories: structural projects, ice removal and suppression, and floodplain regulations.

- The structural projects involved levees and floodwalls. Because of cost, these structures were constructed in high-damage areas only, and did not protect the entire floodplain. Dam and reservoir construction was deemed too costly.
- Ice removal and suppression efforts centered around the confluence of Cazenovia Creek with the Buffalo River, where strong, thick ice prevented passage of upstream ice during spring breakup. In principle, keeping this area clear would eliminate ice jamming and the resulting flooding. To that end, a 308 × 21.5 × 2.5-m (1000 × 70 × 8-ft) channel was excavated in the creek in the hope of reducing ice production. In addition, thermal discharge to melt the ice and blasting of deposited ice were also attempted, but with limited success. In 1964, the city began using amphibious icebreaking craft to break the ice and help it flow downstream into the Buffalo River and eventually into Lake Erie. This technique periodically required the help of a Coast Guard icebreaker on the Buffalo River to provide a channel for ice passage.
- Zoning regulations were established to limit construction on the floodplain. Those areas that were developed were subject to minimum first-floor elevations determined by the 1959 flood levels.

Throughout the early 1960s, ice-jam prevention efforts continued with few restrictions. However, in January 1966 the New York State Legislature imposed strict guidelines on river projects. A permit process was implemented to regulate dam rehabilitation or any modification to river channels. In the years that followed, the level of flood protection was inadequate. Seven ice-jam floods were recorded between 1971 and 1982.

An ice-jam flooding prevention plan was prepared by the U.S. Army Corps of Engineers, Buffalo District, with two options. The first option recommended construction of additional levees and floodwalls and a drainage system.

The second option proposed building an ice control structure (ICS) that would hold ice in the creek so it would at least partially melt in place, reducing the amount of ice carried downstream and delaying the ice run long enough for most, if not all, the ice in lower Cazenovia Creek and the Buffalo River to have flowed out into Lake Erie. The ICS was to be located in an undeveloped area where the left bank of the creek was dominated by high cliffs and there was a flood plain on the right bank (Figure 1).

The city of West Seneca and the New York Department of Environmental Conservation requested that a physical hydraulic model study of the proposed ICS be conducted to evaluate its performance before actual construction.

The model study of the proposed Cazenovia Creek Ice Control Structure was conducted in the refrigerated Research Hydraulic Facility of the Ice Engineering Facility of the Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire. This report describes the design, execution, and results of this model study, which led to the eventual acceptance of the proposed ICS by the COE Buffalo District.

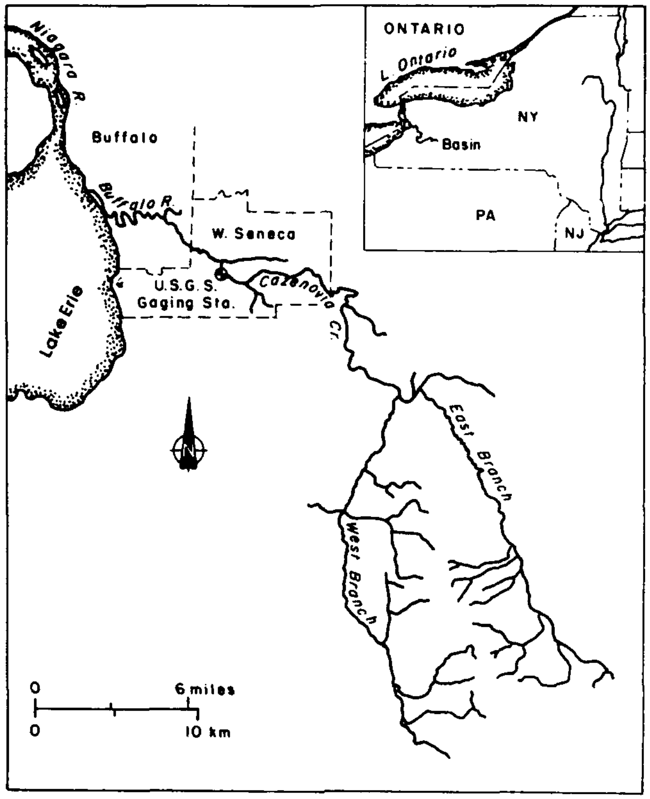


Figure 1. Map of Cazenovia Creek watershed.

PHYSICAL MODELS

River ice breakup on Cazenovia Creek is similar to that on other Northeast rivers. The key elements needed to cause serious ice-jam flooding are outlined in Figure 2.

Physical models used to study natural phenomena of flowing fluids must in principle satisfy the requirements of geometric similarity, dynamic similarity, and kinematic similarity. Geometric similarity requires that the model reproduces the physical layout of the prototype. Dynamic similarity implies that the ratio of any two forces acting at the prototype scale is reproduced in the model, while kinematic similarity means that flow patterns (i.e., streamline and pathline configurations) in the prototype are reproduced at the model scale. While geometric and dynamic similarities result in kinematic similarity, the converse is not necessarily true, that is, geometric and kinematic similarities do not necessarily result in dynamic similarity.

It can be shown that, for all three similarities to be fully achieved, the only possible geometric scale of a model is 1—that is, the prototype is the model! Therefore, some of the modeling criteria or constraints must be relaxed. To this end, only those forces that dominate the phenomena under study, such as gravity and inertia, are modeled correctly. Other secondary forces, such as viscous and surface tension forces, are only approximated within reasonable limits (for example, model flow will be turbulent but at a significantly lower Reynolds number than in the prototype).

> Because all relevant scaling parameters cannot be simultaneously satisfied, a successful model requires a balance of forces and material properties to reproduce the prototype processes of most concern. The design of such a model requires a coherent selection of both materials and scaling ratios that will result in ice and hydraulic behavior that is generally similar to that observed in the prototype for the required range of conditions. The importance of verification against field data cannot be overemphasized. (Wuebben, in preparation)

The driving force of channel flow, with or without ice, is gravity. Therefore, the ratio of inertia forces to gravity forces should be equal in the model and the prototype. This dictates equal Froude numbers between

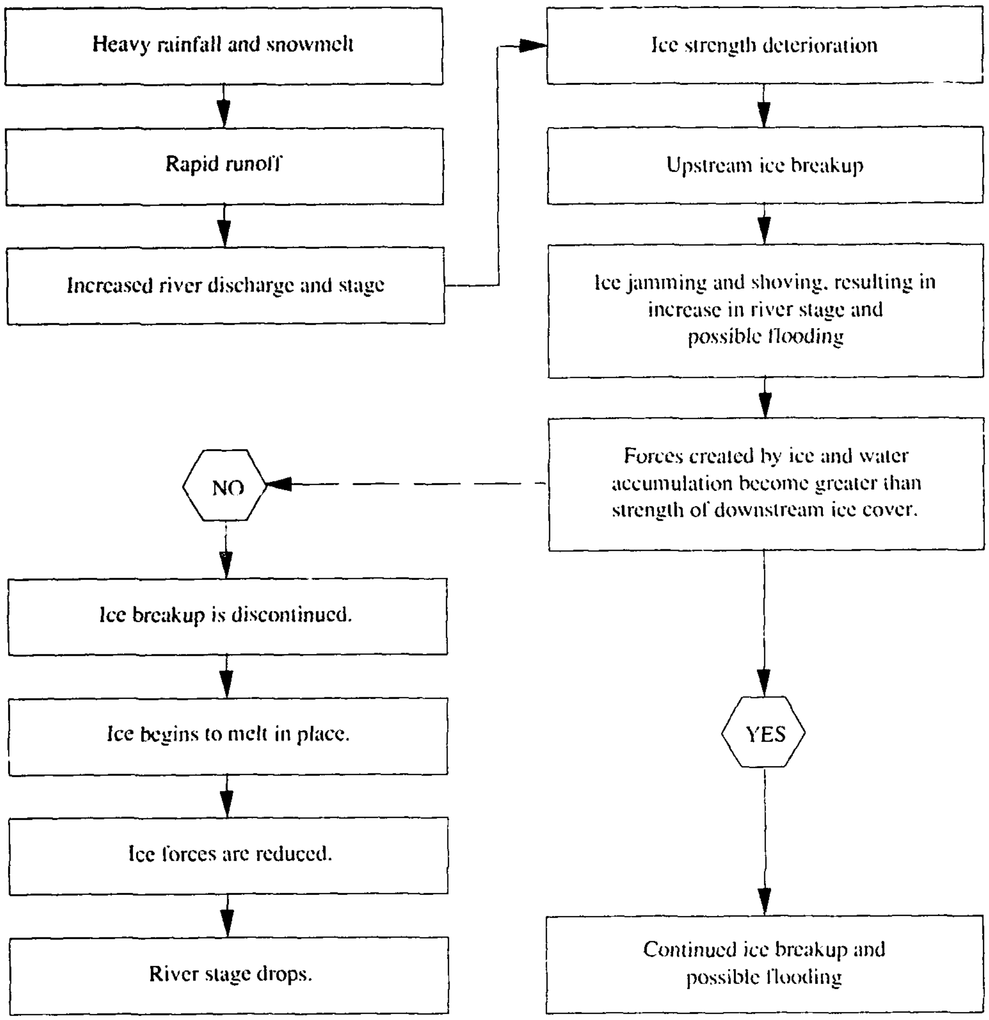


Figure 2. Flow chart of key elements in river flooding.

model and prototype. When an ice cover is present, the ratio of ice forces to gravity forces should also be kept constant, that is the ratio of dimensionless ice strengths at both scales should also be equal to one:

$$F_r = V_r / \sqrt{g_r\, d_r} = 1 \qquad (1)$$

$$C_r = \frac{\sigma_r\, h_r^2}{\rho_r\, g_r\, h_r\, L_r^2} = 1 \qquad (2)$$

where V_r = velocity ratio = V_p/V_m
g_r = gravity ratio = $g_p/g_m = 1$
L_r = characteristic horizontal length ratio = L_p/L_m
d_r = flow depth ratio = d_p/d_m
h_r = ice thickness ratio = h_p/h_m
ρ_r = density ratio (water or ice) = $\rho_p/\rho_m = 1$
σ_r = ice strength ratio = σ_p/σ_m

subscripts: r = full scale/model scale
p = prototype (full scale)
m = model

To achieve true geometric similarity, an undistorted model is required. However, the extent of the area to be modeled may be so large or the size of the available laboratory so limited that in the resulting model scale the flow depth, in particular, becomes much too small to ensure turbulent flow in the model. A geometrically distorted model must then be used, that is, the scale in the vertical direction, β, will be smaller than that in the horizontal plane, λ. Model distortion, λ/β, should be

Table 1. Scaling laws for the Cazenovia Creek model.

	Formula/ symbol	*Scale*
Horizontal	λ	λ
Vertical	β	β
Length, horizontal	L	λ
Length, vertical	Y	β
Area, horizontal	A_h	λ^2
Area, vertical	A_v	$\lambda\beta$
Volume	V	$\lambda^2\beta$
Time	t	$\lambda/\beta^{1/2}$
Mass	M	$\lambda^2\beta$
Density	ρ	1
Gravity	g	1
Velocity	v	$\beta^{1/2}$
Acceleration	a	1
Water discharge	Q	$\lambda\beta^{3/2}$
Water depth	Y	b
River slope	S	β/λ
Head losses	$f - \frac{V^2 L}{4gY}$	β
Friction factor	f	β/λ
Horizontal friction force	$f\rho v^2L^2$	$\lambda\beta^2$
Vertical hydrodynamic forces (lift)	ρv^2L^2	$\lambda^2\beta$
Gravity forces (vertical)	ρgL^2Y	$\lambda^2\beta$
Gravity forces (horizontal)	ρgL^2ys	$\lambda\beta^2$
Flexural failure force (vertical)	$F_b = \sigma h^2$	$\lambda^2\beta$
Ice flexural strength	σ_f	λ^2/β

Table 2. Cazenovia Creek ice-jam floods since 1971.

Date	*Prototype discharge* (m^3/s)	(ft^3/s)	$\lambda\beta^{3/2}$ *Model discharge* (m^3/min)	(gal/min)
3/27/71	877.8	3100	4.16	1099
3/02/72	1642.4	5800	7.79	2057
1/21/74	538.0	1900	2.55	674
2/17/76	764.6	2700	3.62	957
3/21/78	991.1	3500	4.70	1241
3/04/70	764.6	2700	3.62	957
3/13/82	877.8	3100	4.16	1099

kept as low as possible to minimize adverse effects on the model results and their interpretation.

Once the geometric scale λ, or in the case of a distorted model scales λ and β, are selected, those for any other physical quantities are prescribed by the applicable modeling laws. In the case of channel flow in the presence of ice, where the modeling laws are given by eq 1 and 2, the scales are listed in Table 1.

CAZENOVIA CREEK ICS MODEL

Scale selection

For the present model of the Cazenovia Creek Ice Control Structure, it was considered sufficient to model the reach upstream from the ICS location over a distance of 1290 m (4200 ft). It was anticipated that the backwater curve created by a 1.8- to 2.5-m (6- to 8-ft)-high weir, the ICS concept, would extend 215 to 250 m (700 to 800 ft) upstream; the remainder of the reach would permit calibration of the model under open water conditions and ensure that the flow was well established when it approached the ICS location. The available space in the refrigerated hydraulic model area of the CRREL Ice Engineering Facility was 46 m long by 18.5 m wide (150 × 60 ft). The horizontal scale for the model was therefore selected to be λ = 40:1. At such a scale, the flow depth in the model would have been less than 5 cm (2 in.) at the structure and no greater than 0.3 cm (0.1 in.) in the main reach, since the flow depth in the creek rarely exceeds 61.5 cm (2 ft). Such shallow depths in the model were unacceptable: flow would not be sufficiently turbulent, accuracy in open-water calibration would be low, and flow depth would be quite small as compared to the minimum ice thickness of 2.5 cm (1 in.) that can be grown (see Model Ice below). It was therefore necessary to build a geometrically distorted model. Compromise between minimum acceptable flow depth and maximum available pumping capacity in the model area (7.57 m^3 [2000 gal]/min) dictated a vertical scale of β = 10:1. With λ = 40:1 and β = 10:1, an acceptable distortion ratio of 4 was achieved and the maximum prototype flow discharge that could be modeled was about 1700 m^3 (6000 ft^3)/s, roughly twice the discharge at which complete ice breakup in the creek occurs and about equal to the maximum reported discharge during ice-related floods since 1971 (see Table 2).

Model ice

When model studies involving ice require that mechanical properties of ice be modeled, freshwater ice cannot be used. Instead, ice is grown from a bath of water to which a suitable dopant such as salt, carbamide (urea), or glycol has been added. During ice growth, the dopant is trapped between crystals of pure ice and, with proper techniques for growing and tempering the ice, creates 'brine' pockets that reduce the ice's mechanical properties to the desired levels. Since 1980, the CRREL Ice Engineering Facility has used and tested the urea-doped model ice developed by Timco (1979) as a replacement for saline ice, which caused high levels of corrosion and corresponding maintenance costs. This ice is grown from a 1% solution of urea (or carbamide) in water and has been extensively tested (Hirayama 1983). When the anticipated primary mode of ice failure is in bending, the flexural strength is the mechanical property that must be scaled down. That of the model ice is measured in situ on small cantilever beams of length L = 6 to 8 times thickness h, and with B = 1 to 2 times h. A load is applied at the tip of the cantilever beam until failure. The ice flexural strength σ is calculated from the measured failure load P_f by

$$\sigma = \frac{6P_f L}{Bh^2}$$

Experience has shown that the minimum ice thickness and minimum model ice strength that could be achieved with confidence at the CRREL test facilities were h = 2 cm and σ = 20 kPa, respectively. The maximum sheet ice thickness to be expected in Cazenovia Creek is 45 cm, and freshwater ice at breakup has a flexural strength of the order of 800 kPa. From Table 1, with λ = 40:1 and β = 10:1, the corresponding model values should be h = 4.5 cm and σ = 5 kPa. This model ice flexural strength cannot be achieved. It was therefore decided to adjust the ice thickness in the model so that the overall ice resistance to bending, which is proportional to $\sigma \cdot h^2$, be correctly modeled with the minimum reliable model ice strength of 20 kPa. That is,

$$\sigma_r \cdot h_r^2 = \lambda^2 \cdot \beta$$

with

$$\sigma_r = 800/20 = 40,$$

which led to

$$h_r = 20,$$

giving a target model ice thickness of h = 2.25 cm. In other words, an additional distortion was introduced to be able to model what was considered to be one of the most important forces.

The external forces acting on the ice sheet upstream from the ICS are

a. The buoyancy forces due to the frazil ice and ice floes being transported and accumulated below it, and
b. The lifting force exerted on the upstream edge of the ice cover as a flood wave passes by.

The former force will be properly modeled by ensuring that enough ice is carried underneath the model ice sheet, the latter by reproducing characteristic hydrographs.

Model construction

Construction of the model began in February 1984 with the placement of plywood templates reproducing 40 cross sections of Cazenovia Creek upstream from the ICS site. Plastic piping was installed along the model riverbed to monitor the water level at 8 locations. A sand base followed by a 7.6-cm (3-in.) mortar surface was applied between the templates. The mortar surface was sealed with fiberglass. The model (Fig. 3) was completed in June 1984.

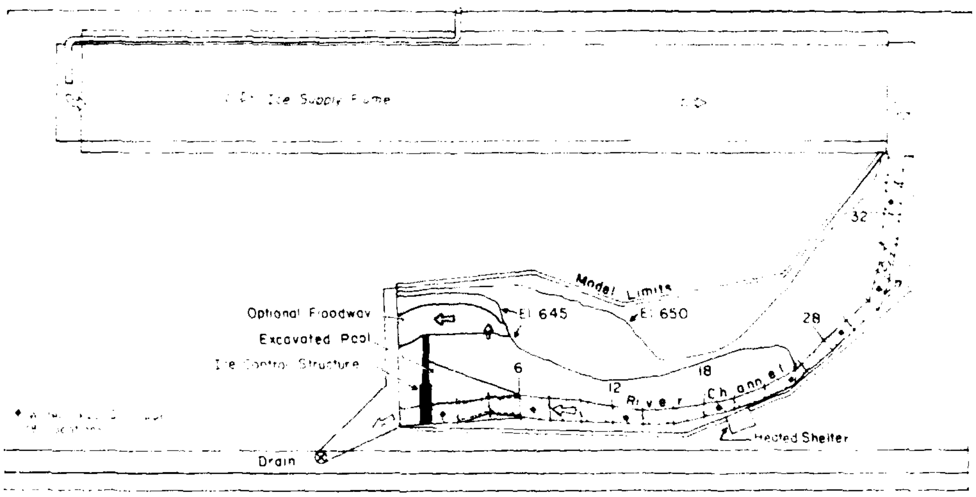


Figure 3. Plan view of Cazenovia Creek model.

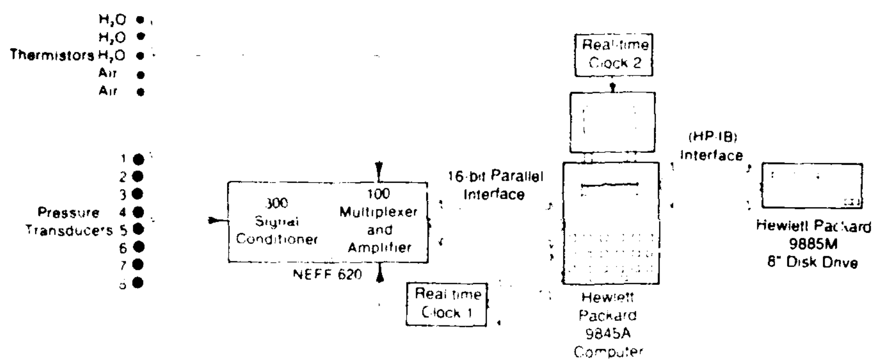


Figure 4. Schematic of data acquisition system.

Data acquisition system

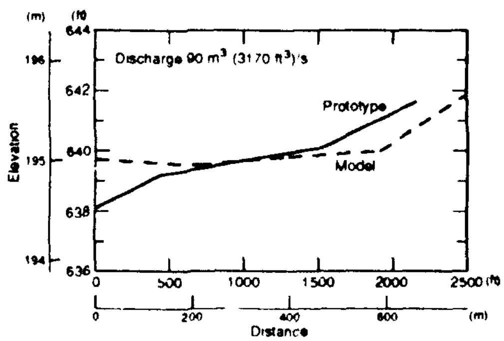
The data acquisition system consisted of thermistors, with an accuracy of 0.02°C, to monitor air and water temperatures, and 8 absolute pressure transducers to monitor water-level changes in the 8 standpipes embedded in the model. These pressure transducers, which had an accuracy of 0.3 cm (0.01 ft) of water, were necessary to evaluate the performance of the ice control structure by recording rapid water-level changes in the creek during ice-breakup simulations. The thermistors and pressure transducers were connected to a NEFF 620 signal conditioner and multiplexer controlled by an HP9845A computer. Group calibration check of the pressure transducers was accomplished by connecting all 8 transducers to a common standpipe with a known water level. The output of the transducers was checked against their calibration to detect any inaccuracies.

This data acquisition system, shown in Figure 4, has been described in detail by Bennett and Zabilansky (1985). It had three major advantages:

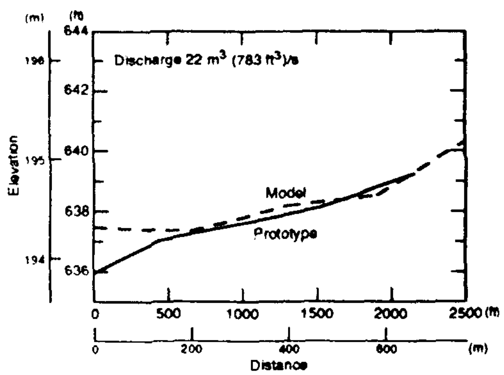
a. It permitted real-time graphic display of water surface hydrographs at all monitoring locations. Changing water levels were recorded at 4-s intervals, permitting the ice jam to be located as it released or subsided.
b. It provided a permanent record of all measurements for subsequent analysis and interpretation.
c. The data base was calibrated and corrected through the software's initial short/shunt calibration.

Model calibration

Before conducting tests with the ICS model, the Cazenovia Creek model was hydraulically calibrated by matching in the model water surface elevations measured in the prototype at two levels of discharge. Discharges of 898 and 222 m^3(3170 and 783 ft^3)/s in the prototype were scaled down to model values of 4.25 and 1.05 m^3 (1124 and 278 gal)/min, respectively. As is often the case in distorted hydraulic models, the bed



a. Q = 3170 ft³/s.



b. Q = 783 ft³/s.

Figure 5. Model calibration: comparison of water surface profiles between model and full-scale.

roughness of the model had to be increased by laying a plastic fencing material on the channel surface until model water elevations were in agreement with those measured in the field. Results of the calibration are shown in Figure 5.

TEST CONDITIONS AND PROCEDURES

Since flow records for Cazenovia Creek indicated that ice breakup occured when the flow discharge reached approximately 425 m^3 (1500 ft^3)/s, this value was used as the base flow condition in all model tests.

The 3-hr unit hydrograph used in the model was selected as the average of two unit hydrographs that represented the following conditions:

- Known uniform rainfall and distribution
- Unfrozen ground preceding the rainfall
- Bankful peak stage.

This hydrograph (Fig. 6) was considered to be representative of extreme conditions that could be expected. To reproduce this hydrograph in the model according to the scaling factor for time in the flow direction, it was determined that the discharge in the model had to increase linearly from the base flow of 1.89 m^3 (500 gal)/min (425 m^3 [1500 ft^3]/s at full scale) to the maximum possible 7.95 m^3 (2100 gal)/min (1700 m^3 [6000 ft^3]/s full scale) in approximately 15 minutes.

The model represents a 1230-m (4000-ft) reach upstream from the ICS site. However, it was estimated that at breakup ice reaching the ICS site originated as much as 12.8 km (8 miles) upstream. Therefore the shallow flume in the Hydraulic Research Area was used to supply brash ice to the model during the tests.

Test conditions

The initial ICS height was selected to be 1.8 m (6 ft) at full scale and its width to be 77 m (250 ft). The corresponding model was placed at station 0+00 (Fig. 3). In addition, the upstream pool was excavated on the right bank to a width of 123 m (400 ft) at station 0+00, returning to the original right bank at station 6+00 as shown in Figure 1, with all material removed within this area to elevation 635. The ICS height and pool excavation increased the cross-sectional flow area sufficiently to achieve the ice stability criteria of 0.566 m^3 (2 ft^3)/s up to a discharge of approximately 906 m^3 (3200 ft^3)/s. A Buffalo District report (1975) had found these conditions to be economically acceptable.

To help contain the ice during higher discharges, vertical piers were mounted on the top of the structure (Fig. 7). Tests were made with 2, 3, 5, and 9 equally spaced piers to determine the optimum configuration. A few tests were conducted with the height of the weir

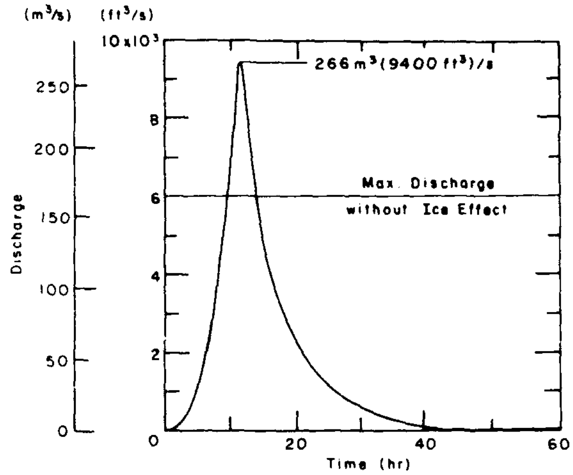


Figure 6. Three-hour unit hydrograph for Cazenovia Creek at Ebenezer.

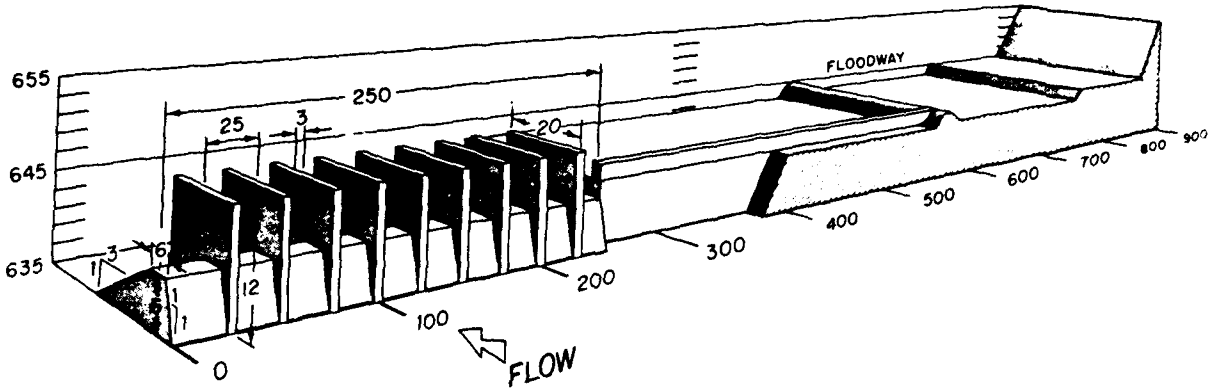
increased to 2.5 m (8 ft), for the cases of no piers and two piers.

Finally, four tests were conducted with 9 piers on the 6-ft structure and an additional 61.5-m (200-ft)-wide bypass floodway constructed on the right bank of the creek to route water around the ICS at the higher discharges. This reduces the effective discharge passing over the weir, resulting in an ice cover stable at higher total discharge than without the floodway.

Table 3 lists the test conditions as weir height, number of piers, ice thickness, and ice strength.

Test procedure

Before each test, the base flow of 1.89 m^3 (500 gal)/min was established in the model, and the room temperature was set at −10°C. When the water temperature had reached nearly the freezing point, a fine water mist was sprayed in the air. The droplets froze into ice crystals, which settled on the water surface to initiate the ice cover in the model and in the ice supply flume. The ice was grown until it reached the desired thickness. The room temperature was raised to about + 1°C to temper the ice until the desired ice strength was reached. The ice sheet in the supply flume and the upstream end of the model was then broken into small fragments. The data acquisition program was started, the flow discharge was increased in steps, and ice was released from the supply flume into the model. The flow was increased until the ice sheet in the pool immediately upstream from the ICS broke up and the accumulated ice started to spill over the structure. The discharge and stage at which this final breakup occurred was recorded, and the test was terminated.



a. Isometric drawing.

b. Photo of model test of 6-ft structure with 2 piers.

Figure 7. The Cazenovia Creek ice control structure.

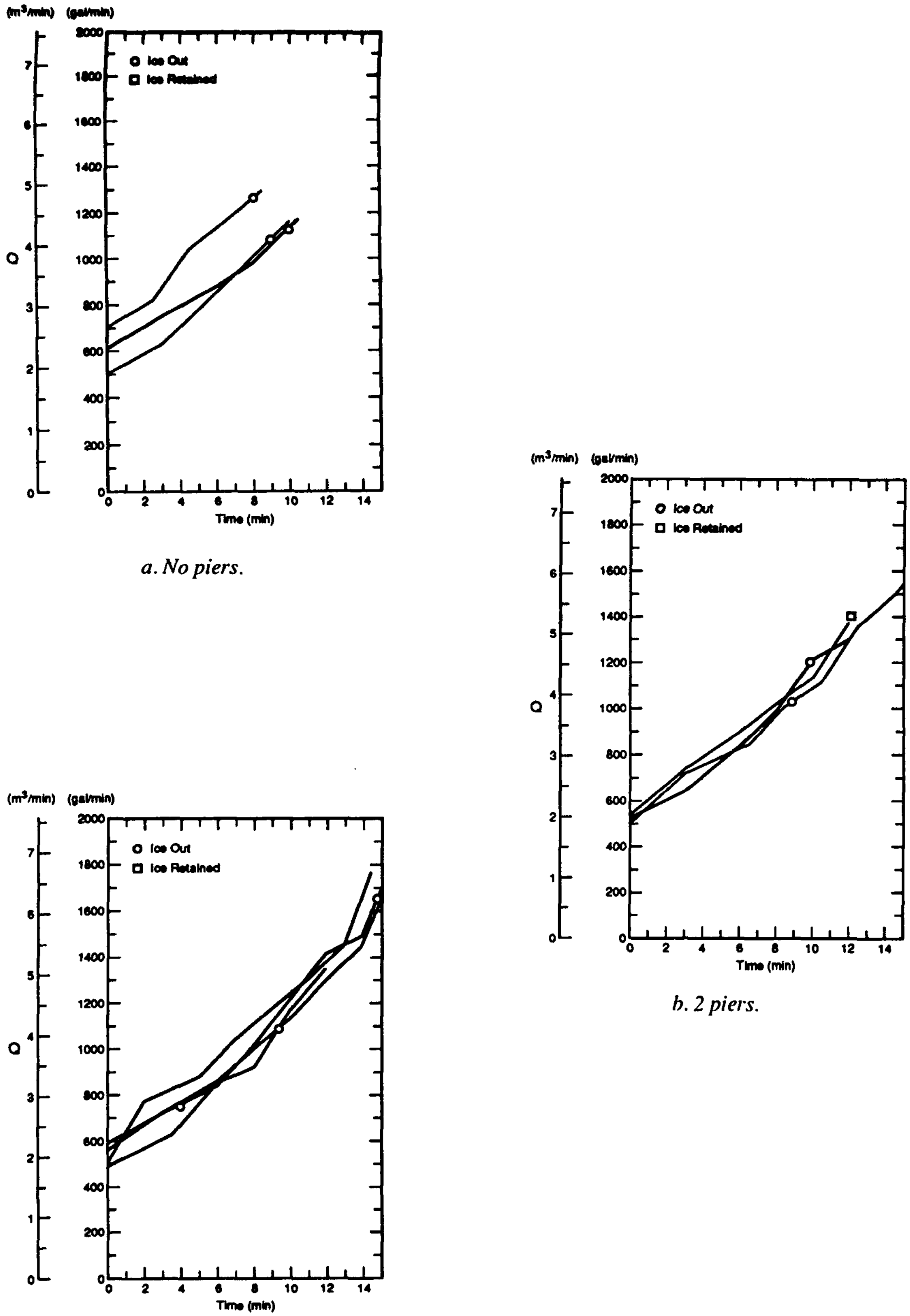
Table 3. Test conditions for Cazenovia Creek model.

Test	*Prototype structure height (ft)*		*Ice strength (kPa)*	*Std dev*	*Ice thickness (mm)*
AA	6	Without piers	17.8	7.9	14.3
BB	6		20.7	5.1	24.9
CC	6		—	—	—
DD	6		16.6	1.0	18.4
EE	6		19.1	2.0	22.9
GG	6		23.2	7.2	28.3
HH	6	Two piers	19.2	—	33.1
II	6		22.2	6.2	21.9
JJ	6		27.3	7.6	26.0
LL	6		19.0	3.6	23.0
MM	6		22.6	2.1	22.6
NN	6		24.5	2.8	22.5
KK	6	(fragmented ice)	—	—	—
OO	8	Without piers	20.5	3.2	25.4
PP	8		28.7	4.0	29.3
QQ	8		20.1	1.2	22.8
RR	8		17.7	1.4	25.8
SS	8		20.5	2.2	19.8
TT	8		19.3	2.0	24.5
UU	8	Two piers	22.7	2.1	28.5
VV	8		26.8	4.6	29.7
A1	6	Without piers	23.3	1.9	27.1
A2	6		11.8	1.2	26.6
A3	6		16.4	4.1	25.8
A4	6	Two piers	20.7	2.0	24.5
A6	6		26.4	2.8	19.0
A5	6	(fragmented ice)	—	—	—
A7	6	Three piers	30.0	6.5	13.6
A8	6		22.8	7.8	25.8
A9	6		25.3	4.2	15.9
B1	6		25.4	2.1	19.8
B2	6	Five piers	26.6	5.7	19.3
B3	6		38.2	3.1	28.8
B4	6		40.3	7.7	26.4
B5	6		28.0	3.3	17.6
B6	6	Nine piers	34.1	4.3	24.2
B7	6		—	—	—
B8	6		—	—	—
B9	6		—	—	—
C1	6	Nine piers and floodway	—	—	—
C2	6		—	—	—
C3	6		—	—	—
C4	6		—	—	—

TEST RESULTS AND DISCUSSION

The model hydrographs for the tests run with the 6-ft ICS are shown in Figure 8 for the various test configurations. In particular, Figure 8f shows the hydrographs for the tests with nine piers and the additional floodway. On these figures it is indicated when ice-out occurred or whether ice was still retained at the end of the test. The corresponding stages at station 0+96 are shown in Figure 9a–c.

The test results (see the Appendix) indicate that although the holding time for ice was increased when additional piers were mounted along the top of the ICS, ice continued to pass through until the number of piers

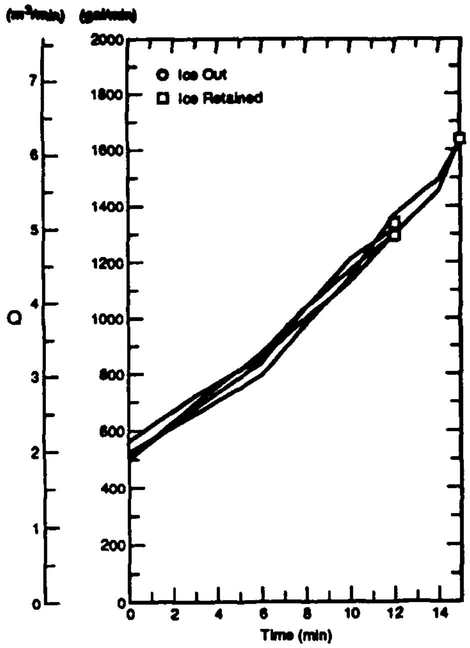


a. No piers.

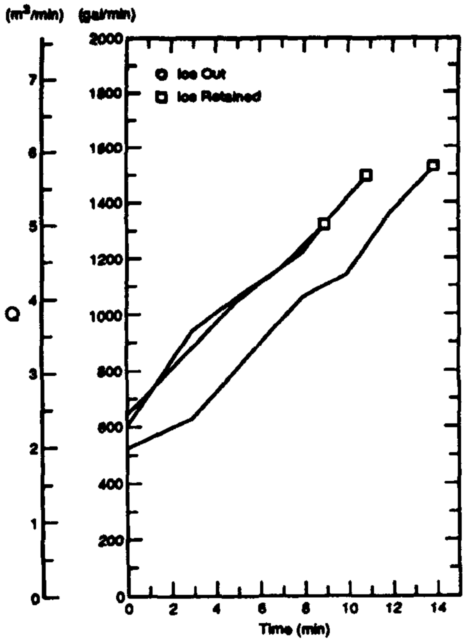
b. 2 piers.

c. 3 piers.

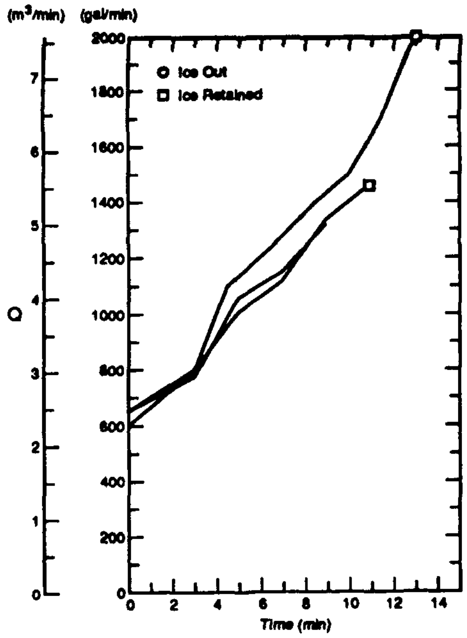
Figure 8. Hydrographs in model tests with 1.8-m (6-ft) ICS.



d. 5 piers.

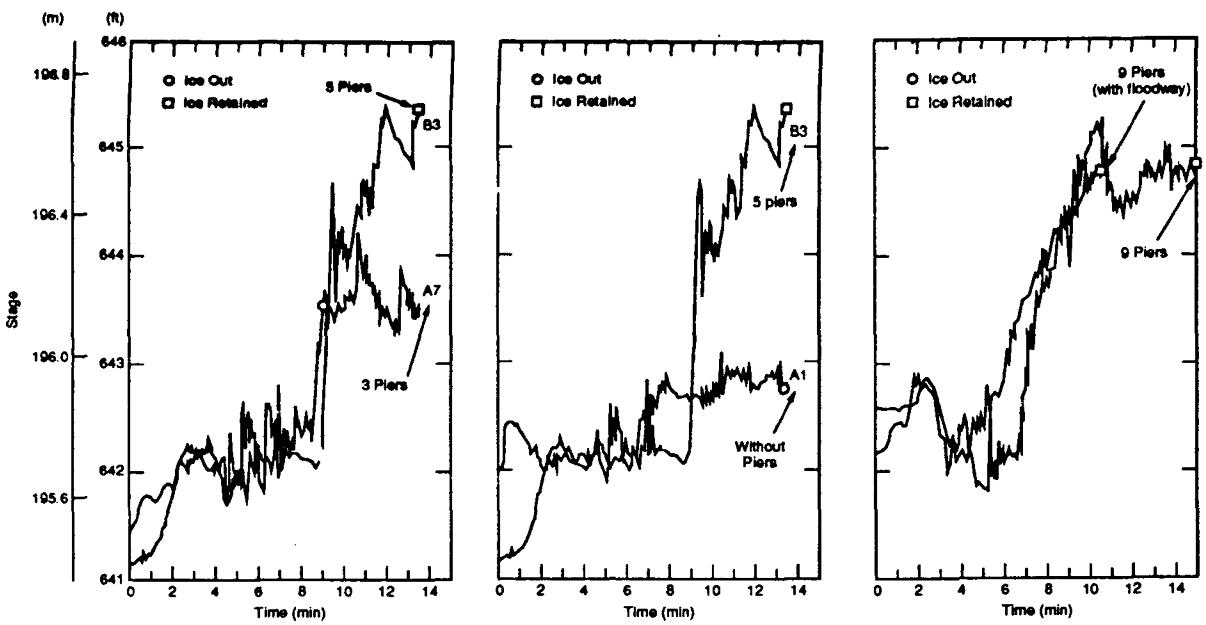


e. 9 piers.



f. 9 piers and floodway.

Figure 8 (cont'd). Hydrographs in model tests with 1.8-m (6-ft) ICS.



a. 3 and 5 piers. *b. No piers and 5 piers.* *c. 9 piers with and without floodway.*

Figure 9. Stage variations at station 0+96.

reached 5. At this point, ice was repeatedly held behind the structure at flow rates greater than those reported for the last seven ice-jam floods (Table 2). The test series using nine piers produced no apparent benefit over the five-pier configuration, possibly because the discharges required for ice-out could not be reached because of the limited pump capacity. The tests with the bypass floodway showed that water began to enter the bypass when a mean flow of 934 m^3 (3300 ft^3)/s was reached. The flow through the bypass reached 382 m^3 (1350 ft^3)/s at the peak test discharge of 1707 m^3 (6030 ft^3)/s, thereby reducing the effective discharge over the weir by 22%. The maximum water level recorded behind the ICS was 647, and water above the 645 level is rerouted to the existing right-bank flood plain.

It should be noted that in those tests where the maximum available discharge was reached, approximately 50% of the ice had been melted by the time of the maximum flow of 1700 m^3 (6000 ft^3)/s because of the heat input to the water by the pump. However, this effect was not considered detrimental to the test results since it implies weakening of the ice cover and therefore less resistance to breakup, and because a similar process occurs naturally during high runoff at ice breakup.

CONCLUSIONS

Results of the Cazenovia Creek ICS model study showed that a 1.8-m (6-ft)-high weir equipped with nine piers and bordered by a bypass floodway is likely to retain ice well beyond the maximum recorded discharge for ice-jam floods since 1971. We feel confident that such a structure will prevent future ice-jam flooding of West Seneca and Buffalo, New York.

This design was accepted by the U.S. Army Corps of Engineers, Buffalo District, and the structure is currently scheduled for completion by 1990.

Once the structure is built, field data will need to be obtained in the following areas:

- Freeze-up and breakup conditions over several winters
- Ice loads on the structure
- Water levels immediately upstream of the ICS

These data are necessary for comparison with the results of the model study, and for future improvements in the design and techniques of hydraulic models involving ice processes.

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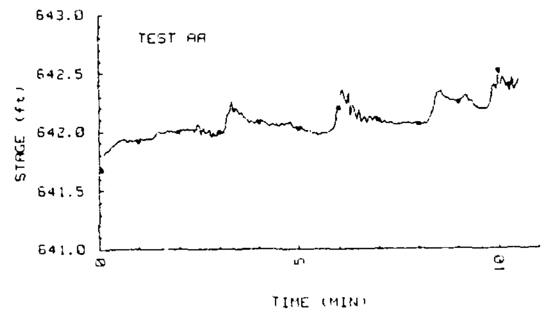
APPENDIX: TEST DATA FOR CAZENOVIA CREEK MODEL STUDY

Plots of experimental data at Standpipe 1
1. Stage vs time
2. Stage vs discharge
Note: *indicates data at 1-min intervals.

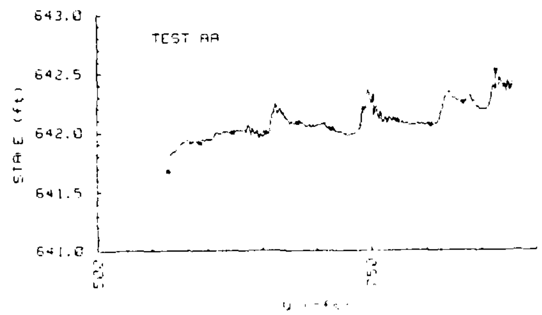
1st TEST SERIES WITH 6-FT ICS - NO PIERS

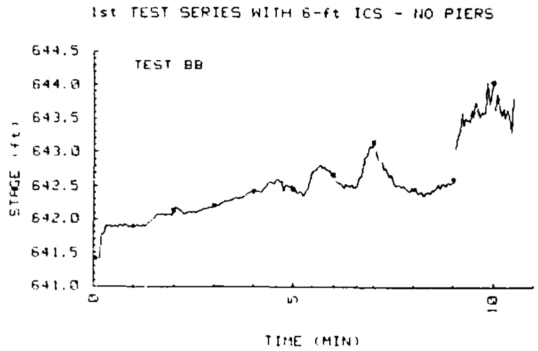
TIME (MIN)	Q (GPM)
TEST # AA	
0.0	200
15.0	350
24.0	580
30.0	740
35.0	900
40.0	1100
TEST # BB	
0.0	280
18.0	560
21.0	700
26.0	1050
TEST # CC	
0.0	360
7.0	555
12.0	1050
TEST # DD	
0.0	100
4.0	250
16.0	640
22.0	1120
TEST # EE	
0.0	200
6.0	420
8.0	[illegible]
11.0	820
13.0	1050
TEST # GG	
0.0	250
9.0	600
13.0	1000
18.0	1250
20.0	1560

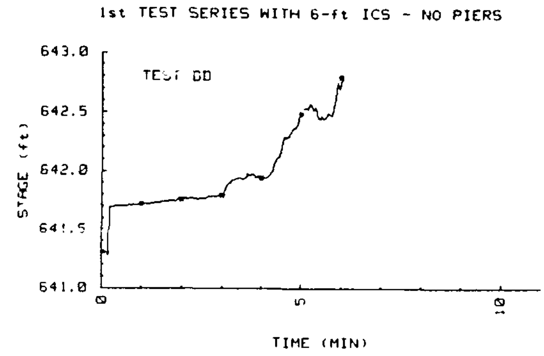
1st TEST SERIES WITH 6-ft ICS - NO PIERS

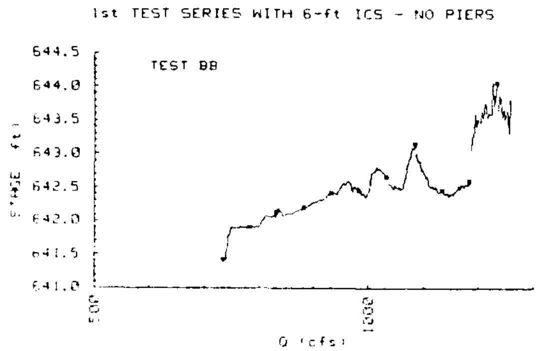


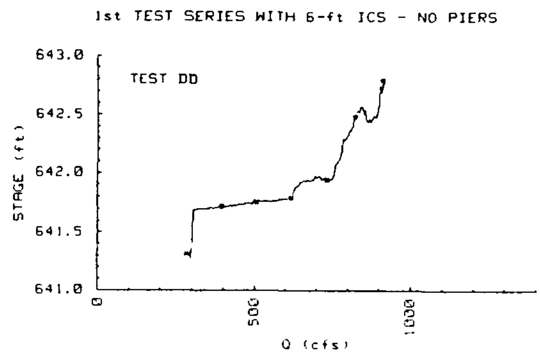
1st TEST SERIES WITH 6-ft ICS - NO PIERS

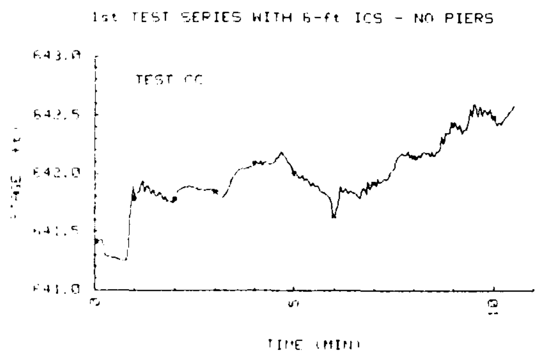


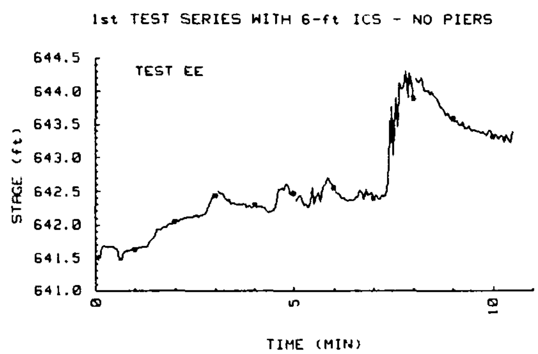

1st TEST SERIES WITH 6-ft ICS - NO PIERS
TEST BB
644.5
644.0
643.5
643.0
642.5
642.0
641.5
641.0
STAGE (ft)
0
5
10
TIME (MIN)

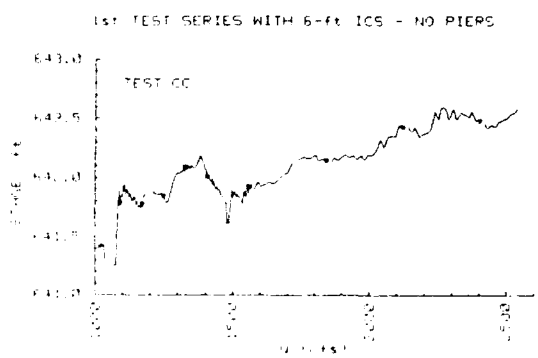

1st TEST SERIES WITH 6-ft ICS - NO PIERS
643.0
642.5
642.0
641.5
641.0
STAGE (ft)
0
5
10
TIME (MIN)

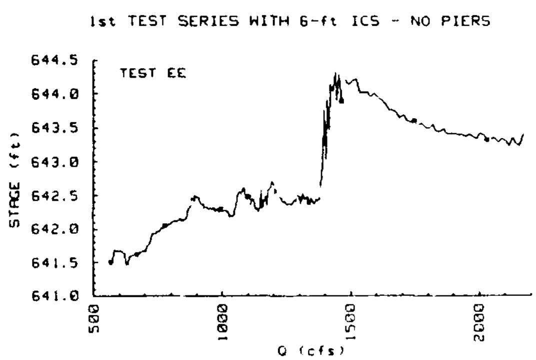

1st TEST SERIES WITH 6-ft ICS - NO PIERS
TEST BB
644.5
644.0
643.5
643.0
642.5
642.0
641.5
641.0
500
1000
Q (cfs)


1st TEST SERIES WITH 6-ft ICS - NO PIERS
TEST DD
643.0
642.5
642.0
641.5
641.0
STAGE (ft)
0
500
1000
Q (cfs)

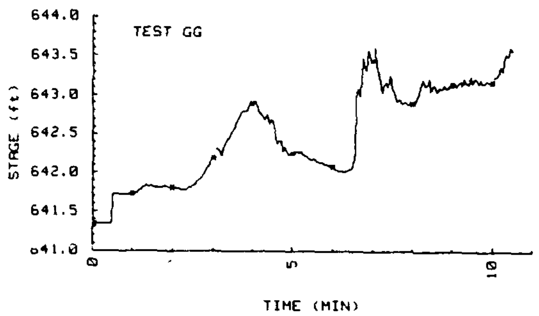

1st TEST SERIES WITH 6-ft ICS - NO PIERS
643.0
642.5
642.0
641.0
0
5
10


1st TEST SERIES WITH 6-ft ICS - NO PIERS
TEST EE
644.5
644.0
643.5
643.0
642.5
642.0
641.5
641.0
STAGE (ft)
0
5
10
TIME (MIN)


1st TEST SERIES WITH 6-ft ICS - NO PIERS


1st TEST SERIES WITH 6-ft ICS - NO PIERS
TEST EE
644.5
644.0
643.5
643.0
642.5
642.0
641.5
641.0
STAGE (ft)
500
1000
1500
2000
Q (cfs)

1st TEST SERIES WITH 6-ft ICS - NO PIERS



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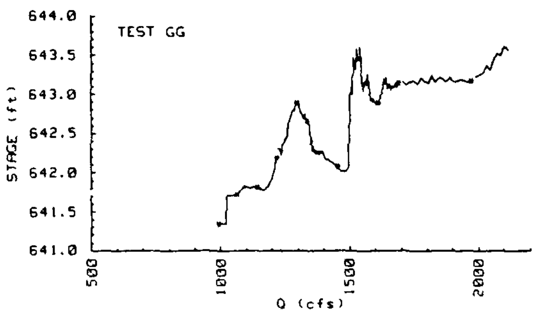
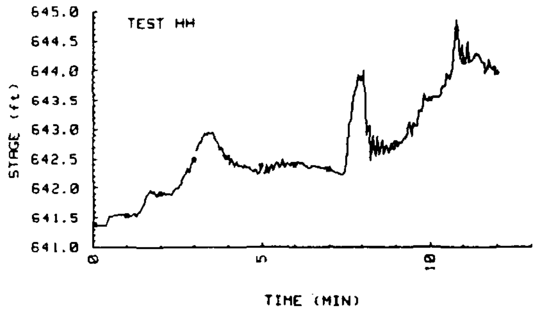


1st TEST SERIES WITH 6-FT ICS - 2 PIERS

TIME (MIN)	Q (GPM)
TEST # HH	
0.0	450
4.0	580
8.0	910
11.0	1160
13.0	1260
16.0	1350
18.0	1590
TEST # II	
0.0	500
3.0	800
8.0	1050
10.0	1240
TEST # JJ	
0.0	620
4.0	940
6.0	1200
9.0	1400
13.0	1720
TEST # LL	
0.0	180
1.0	700
3.5	1040
4.5	1460
5.0	1720
6.0	2000
TEST # MM	
0.0	230
8.0	800
12.0	1020
14.0	1310
15.0	1440
16.0	1630
17.0	1800
19.0	2000
TEST # NN	
0.0	360
16.0	500
19.0	690
22.0	1120
25.0	1590
28.0	1800
TEST # KK	
0.0	640
3.0	920
5.0	1070
5.0	1200
8.0	1370
10.0	1540

1st TEST SERIES WITH 6-ft ICS - 2 PIERS



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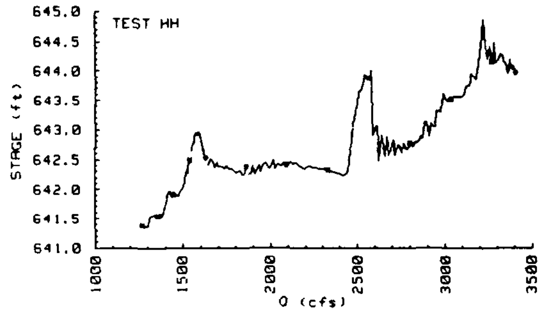

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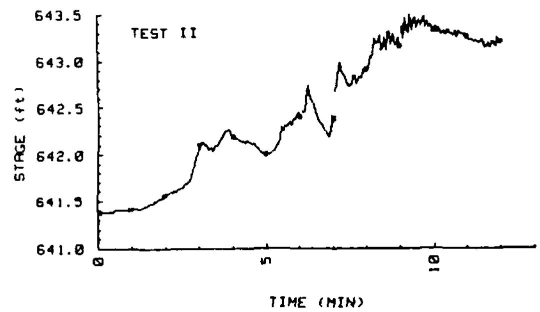
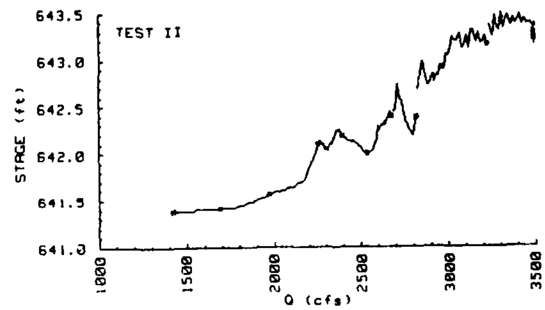


1st TEST SERIES WITH 6-ft ICS - 2 PIERS



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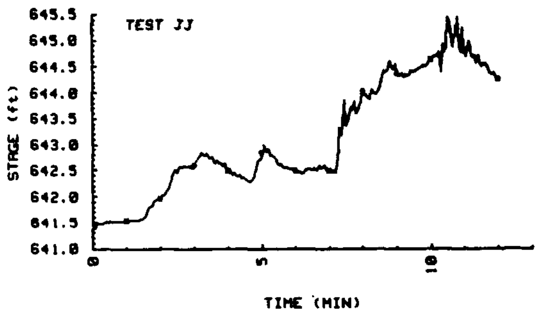

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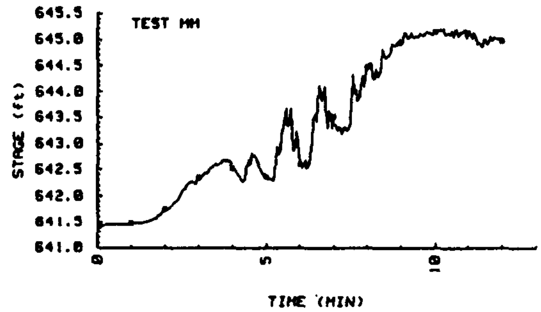

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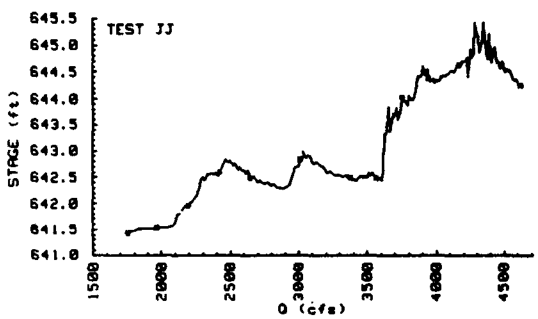
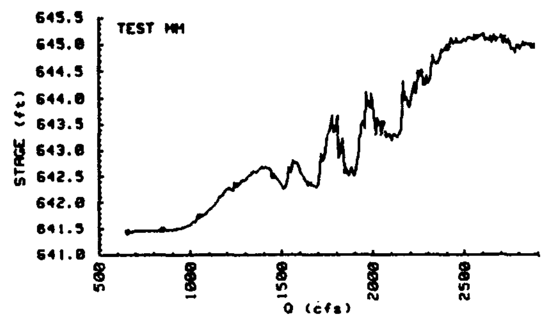
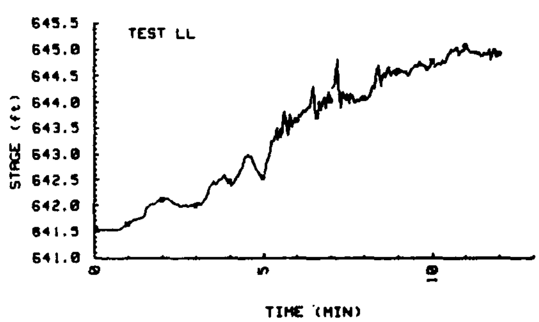


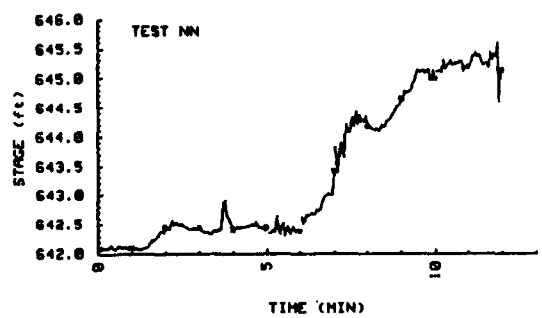
1st TEST SERIES WITH 6-ft ICS - 2 PIERS



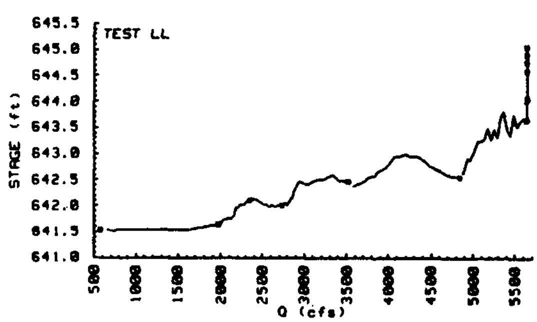
1st TEST SERIES WITH 6-ft ICS - 2 PIERS



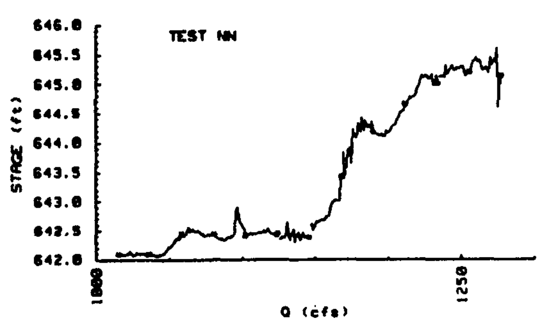
1st TEST SERIES WITH 6-ft ICS - 2 PIERS

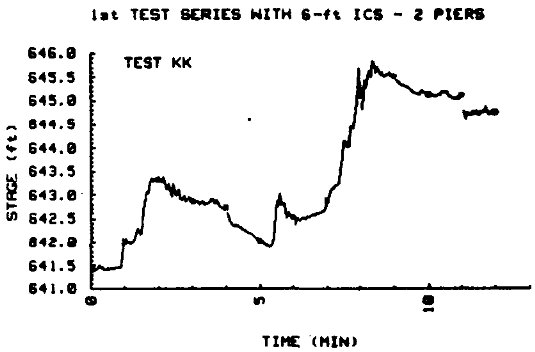


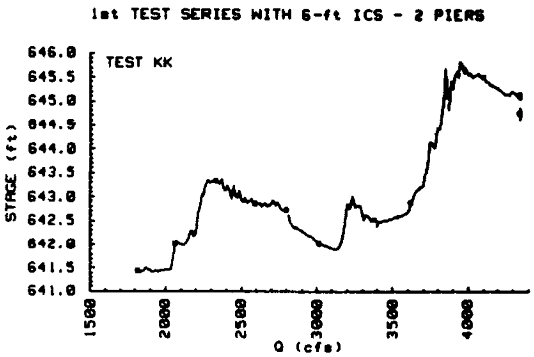
1st TEST SERIES WITH 6-ft ICS - 2 PIERS



1st TEST SERIES WITH 6-ft ICS - 2 PIERS



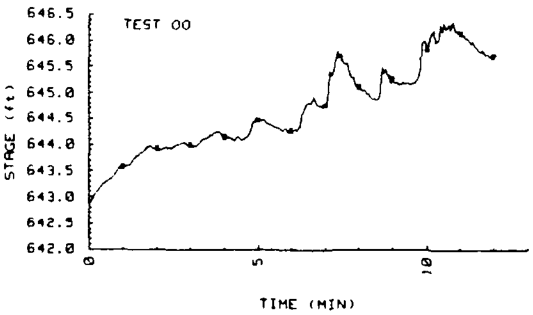

1st TEST SERIES WITH 6-ft ICS - 2 PIERS
TEST KK
STAGE (ft)
646.0
645.5
645.0
644.5
644.0
643.5
643.0
642.5
642.0
641.5
641.0
0
5
10
TIME (MIN)


1st TEST SERIES WITH 6-ft ICS - 2 PIERS
TEST KK
STAGE (ft)
646.0
645.5
645.0
644.5
644.0
643.5
643.0
642.5
642.0
641.5
641.0
1500
2000
2500
3000
3500
4000
Q (cfs)

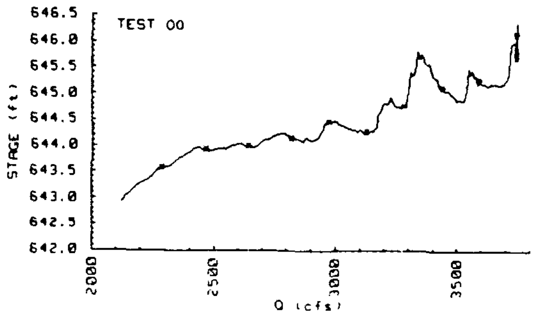
1st TEST SERIES WITH 8-FT ICS - NO PIERS

TIME (MIN)	Q (GPM)
TEST # 00	
0.0	750
4.0	1000
10.0	1350
TEST # PP	
0.0	720
5.0	1020
8.0	1320
11.0	1500
TEST # QQ	
0.0	540
3.0	940
7.5	1030
10.5	1300
TEST # SS	
0.0	350
3.0	820
9.0	1050
13.0	1320
TEST # TT	
0.0	600
2.0	840
12.0	1070
18.0	1460
19.0	1500
23.0	1420

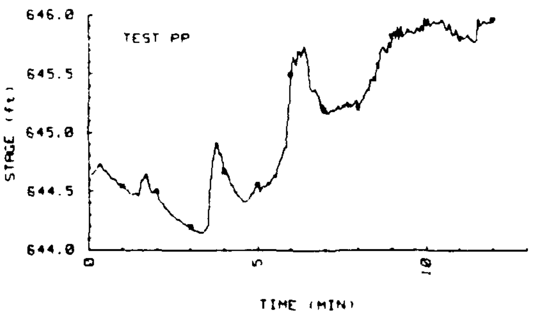
1st TEST SERIES WITH 8-ft ICS - NO PIERS



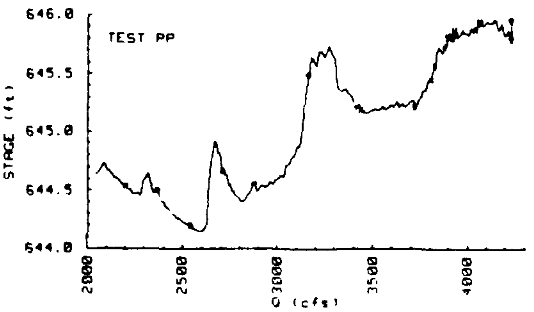
1st TEST SERIES WITH 8-ft ICS - NO PIERS

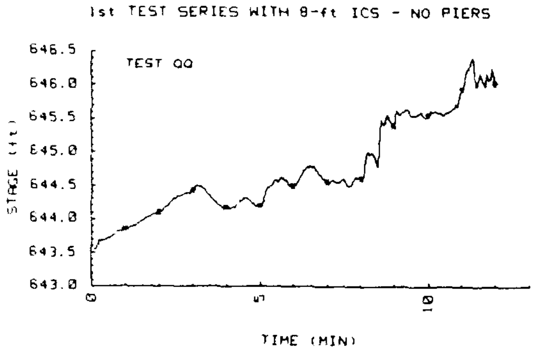


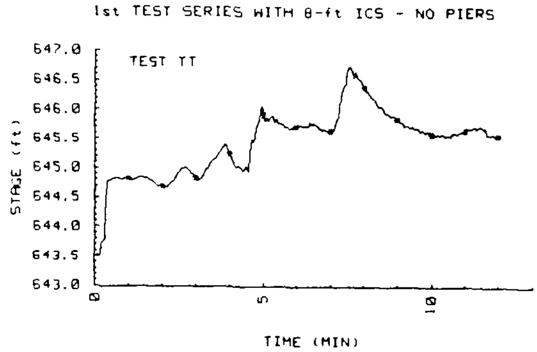
1st TEST SERIES WITH 8-ft ICS - NO PIERS

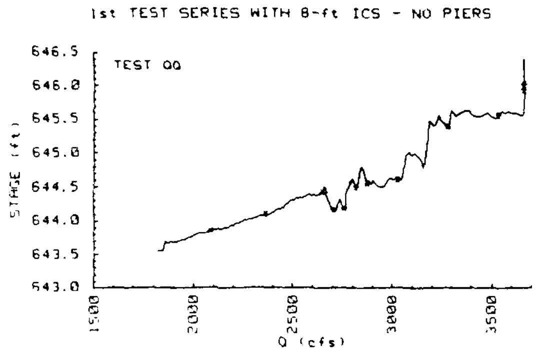


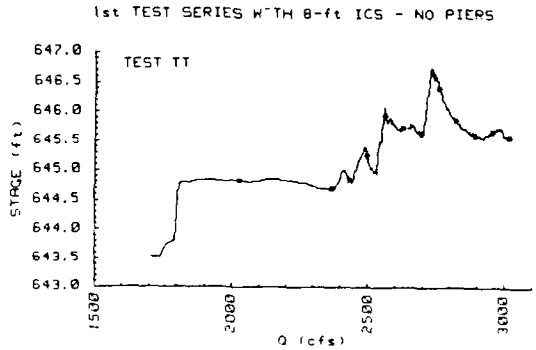
1st TEST SERIES WITH 8-ft ICS - NO PIERS

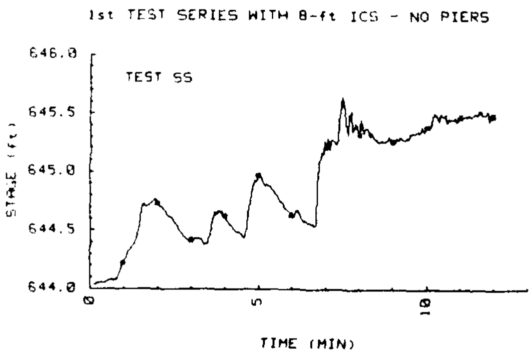


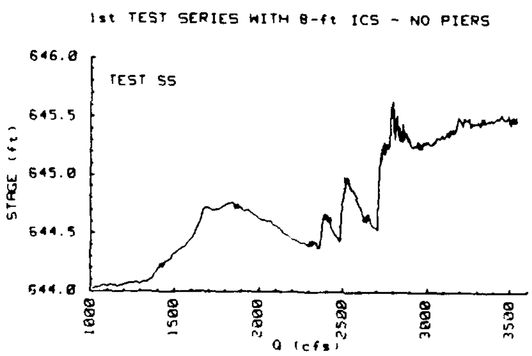

1st TEST SERIES WITH 8-ft ICS - NO PIERS
TEST QQ
STAGE (ft)
646.5
646.0
645.5
645.0
644.5
644.0
643.5
643.0
0
5
10
TIME (MIN)


1st TEST SERIES WITH 8-ft ICS - NO PIERS
TEST TT
STAGE (ft)
647.0
646.5
646.0
645.5
645.0
644.5
644.0
643.5
643.0
0
5
10
TIME (MIN)


1st TEST SERIES WITH 8-ft ICS - NO PIERS
TEST QQ
STAGE (ft)
646.5
646.0
645.5
645.0
644.5
644.0
643.5
643.0
1500
2000
2500
3000
3500
Q (cfs)

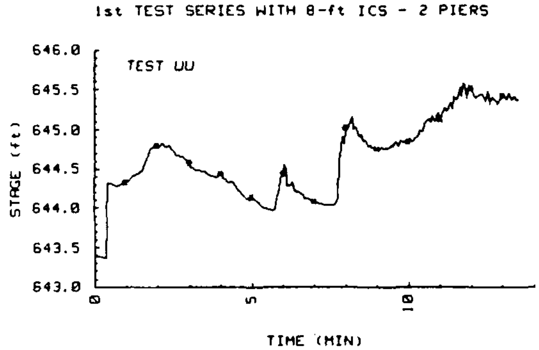

1st TEST SERIES WITH 8-ft ICS - NO PIERS
TEST TT
STAGE (ft)
647.0
646.5
646.0
645.5
645.0
644.5
644.0
643.5
643.0
1500
2000
2500
3000
Q (cfs)

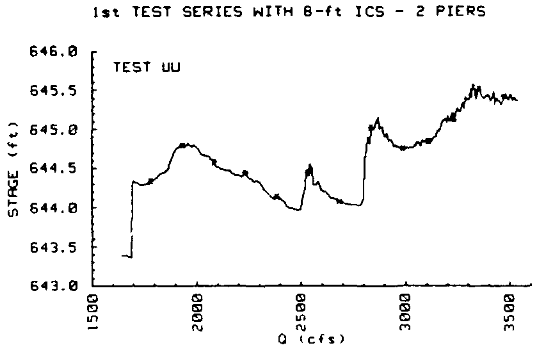

1st TEST SERIES WITH 8-ft ICS - NO PIERS
TEST SS
STAGE (ft)
646.0
645.5
645.0
644.5
644.0
0
5
10
TIME (MIN)

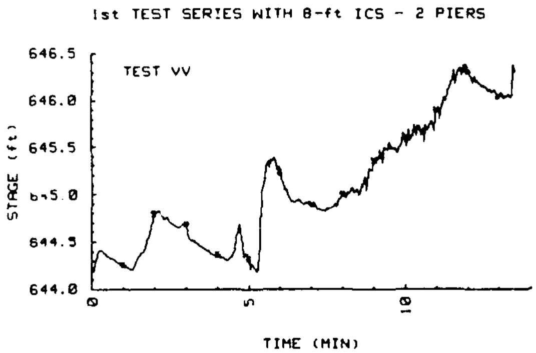

1st TEST SERIES WITH 8-ft ICS - NO PIERS
TEST SS
STAGE (ft)
646.0
645.5
645.0
644.5
644.0
1000
1500
2000
2500
3000
3500
Q (cfs)

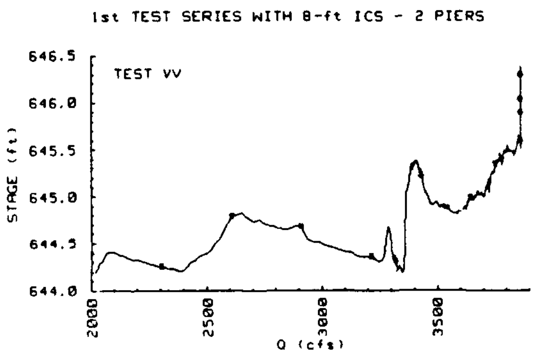
1st TEST SERIES WITH 8-FT ICS - 2 PIERS

TIME (MIN)	Q (GPM)
TEST # UU	
0.0	580
9.0	1060
15.0	1320
TEST # VV	
0.0	710
4.0	1140
10.0	1370





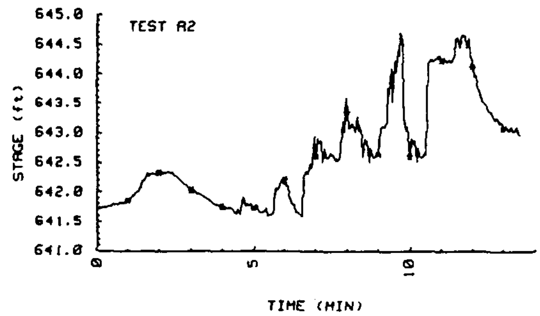




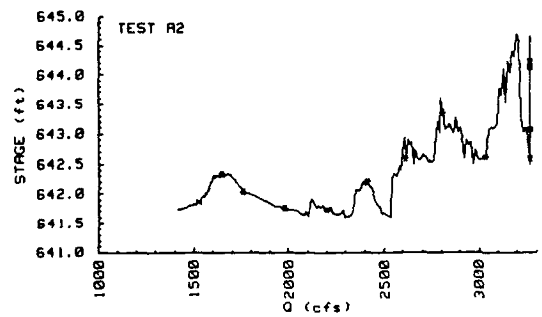
2nd TEST SERIES WITH 6-FT ICS - NO PIERS

TIME (MIN)	Q (GPM)
TEST # A1	
0.0	610
3.0	750
6.0	880
8.0	980
10.5	1170
TEST # A2	
0.0	500
3.0	625
6.5	895
8.0	995
10.0	1160
TEST # A3	
0.0	700
2.5	815
4.5	1040
6.5	1160
8.5	1295

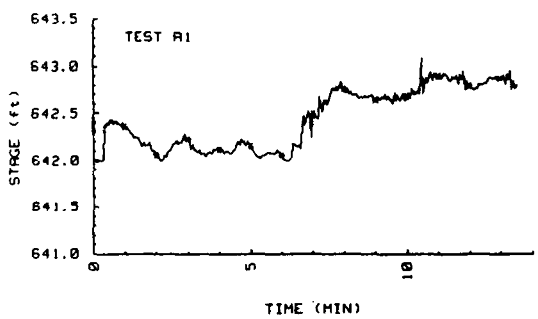
2nd TEST SERIES WITH 6-ft ICS - NO PIERS



2nd TEST SERIES WITH 6-ft ICS - NO PIERS



2nd TEST SERIES WITH 6-ft ICS - NO PIERS



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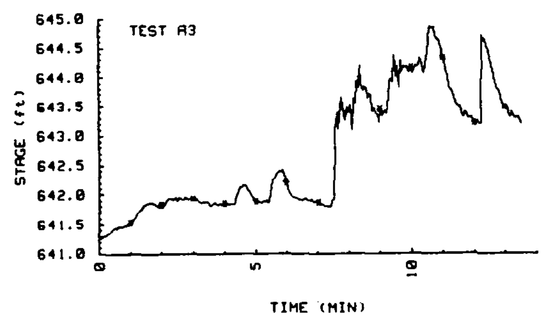

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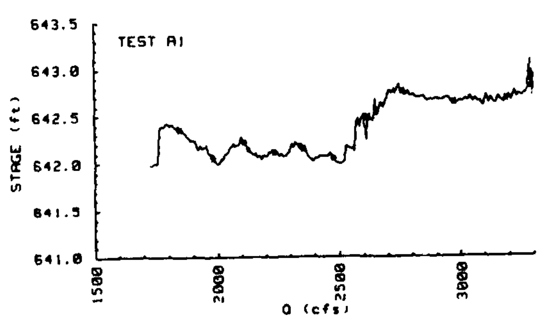

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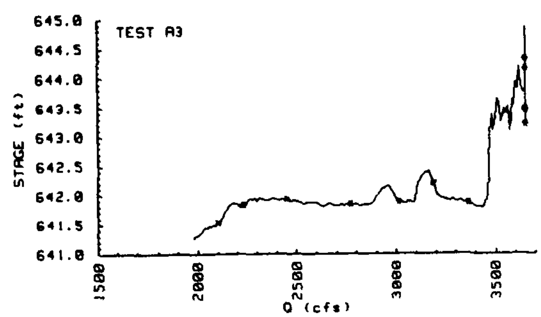
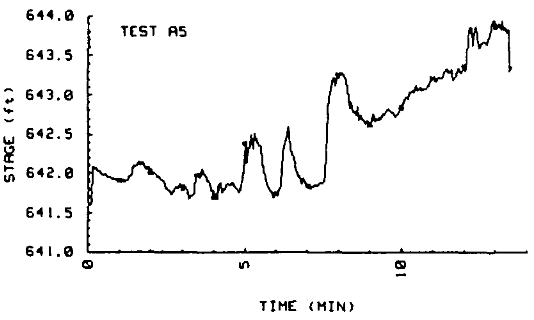


2nd TEST SERIES WITH 6-FT ICS - 2 PIERS

TIME (MIN)	Q (GPM)
TEST # A4	
0.0	540
3.0	735
6.0	900
8.0	1020
10.0	1140
12.0	1370
TEST # A5	
0.0	500
3.0	720
6.5	850
8.5	1010
10.5	1120
12.5	1360
14.5	1500
16.5	1685
TEST # A6	
0.0	525
3.0	640
6.0	840
8.0	990
10.0	1215
12.0	1300

2nd TEST SERIES WITH 6-ft ICS - 2 PIERS



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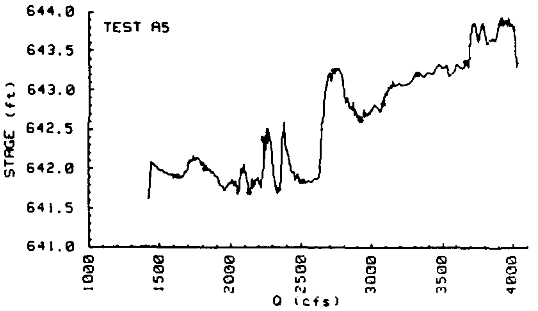

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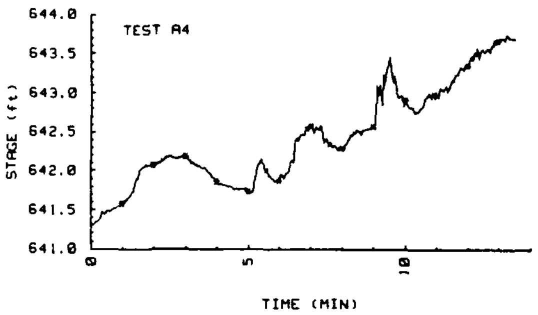

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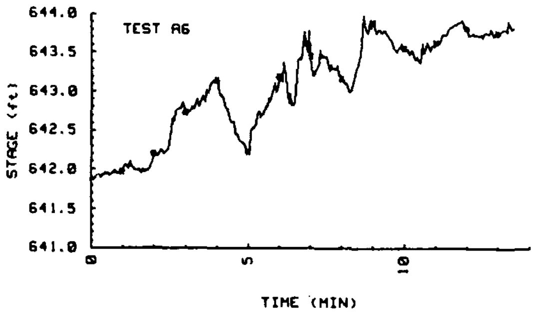

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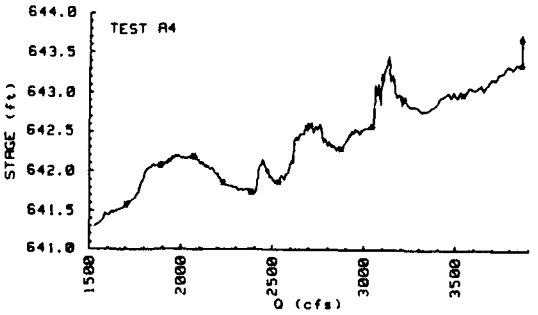

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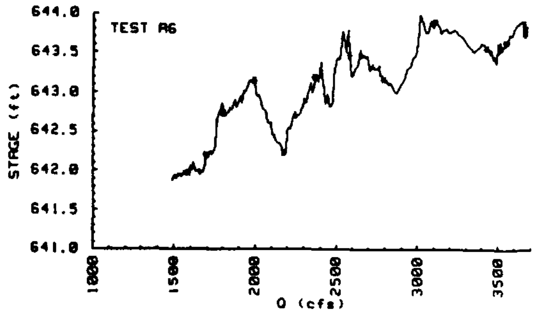


TEST SERIES WITH 6-FT ICS - 3 PIERS

TEST # A7

TIME (MIN)	Q (GPM)
0.0	490
3.5	620
6.0	850
8.0	920
10.0	1160
12.0	1340

TEST # A8

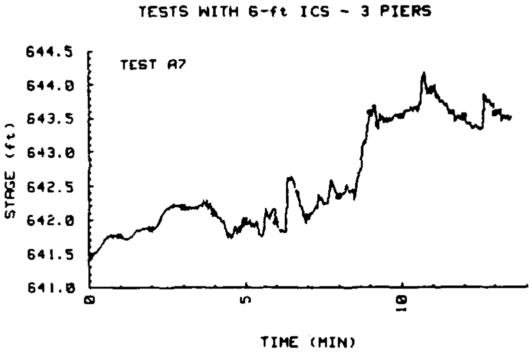
TIME (MIN)	Q (GPM)
0.0	590
3.0	720
6.0	840
8.0	1010
10.0	1210
12.0	1410
14.0	1490
15.0	1680

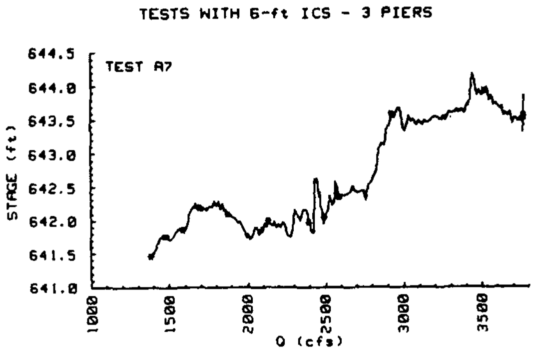
TEST # A9

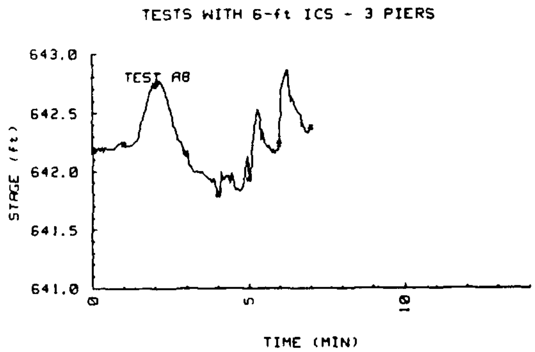
TIME (MIN)	Q (GPM)
0.0	500
2.0	770
5.0	880
7.0	1040
9.0	1170
11.0	1300
13.0	1450
14.5	1760

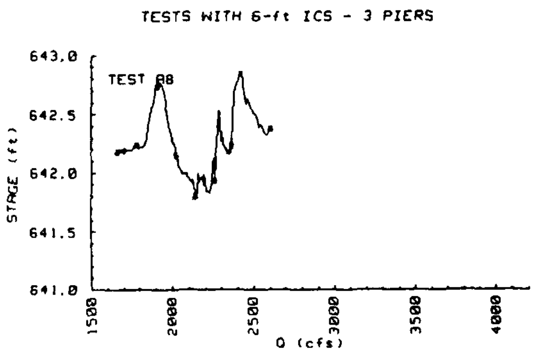
TEST # B1

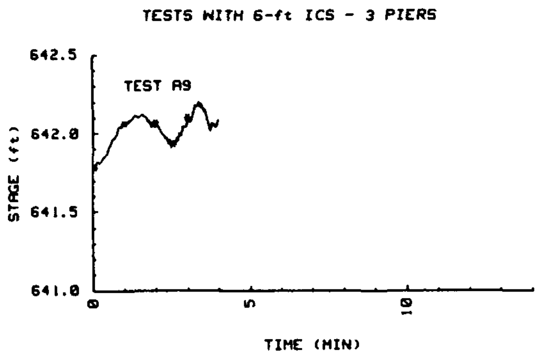
TIME (MIN)	Q (GPM)
0.0	560
3.0	720
6.0	860
8.0	1000
10.0	1130
12.0	1300
14.0	1450
15.0	1640
16.0	1840

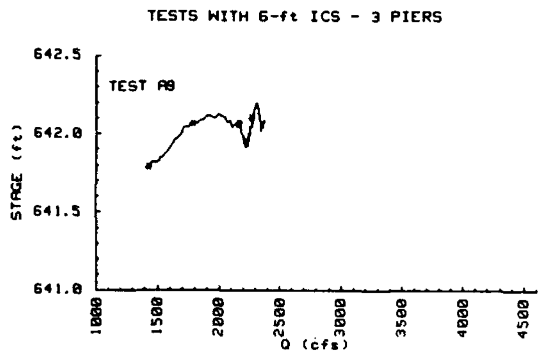


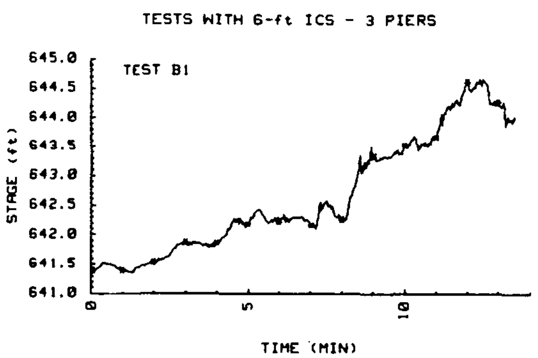


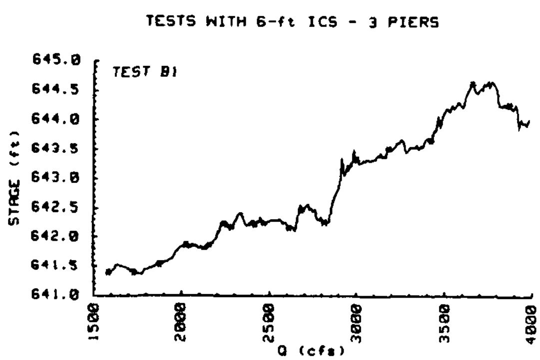





TESTS WITH 6-ft ICS - 3 PIERS
TEST A9
STAGE (ft)
642.5
642.0
641.5
641.0
0
5
10
TIME (MIN)


TESTS WITH 6-ft ICS - 3 PIERS
TEST A9
STAGE (ft)
642.5
642.0
641.5
641.0
1000
1500
2000
2500
3000
3500
4000
4500
Q (cfs)


TESTS WITH 6-ft ICS - 3 PIERS
TEST B1
STAGE (ft)
645.0
644.5
644.0
643.5
643.0
642.5
642.0
641.5
641.0
0
5
10
TIME (MIN)


TESTS WITH 6-ft ICS - 3 PIERS
TEST B1
STAGE (ft)
645.0
644.5
644.0
643.5
643.0
642.5
642.0
641.5
641.0
1500
2000
2500
3000
3500
4000
Q (cfs)

TEST SERIES WITH 6-FT ICS - 5 PIERS

TEST # B2

TIME (MIN)	Q (GPM)
0.0	560
3.0	720
6.0	860
8.0	1000
10.0	1130
12.0	1300
14.0	1450
15.0	1640
16.0	1840

TEST # B3

TIME (MIN)	Q (GPM)
0.0	535
3.0	720
6.0	820
8.0	1040
10.0	1130
12.0	1350
14.0	1490

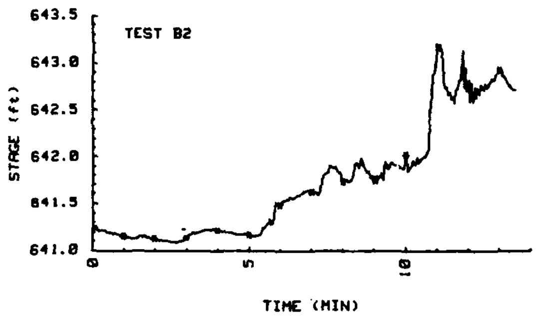
TEST # B4

TIME (MIN)	Q (GPM)
0.0	520
3.0	660
6.0	800
8.0	980
10.0	1140
12.0	1370
14.0	1490
15.0	1630

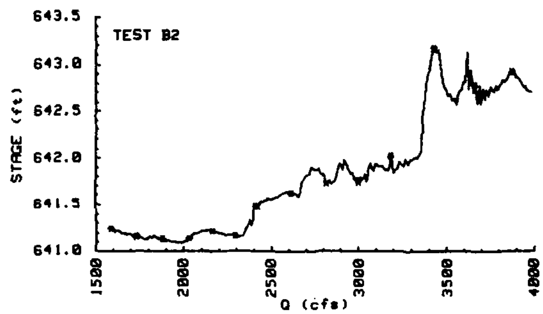
TEST # B5

TIME (MIN)	Q (GPM)
0.0	500
3.0	680
6.0	845
8.0	1040
10.0	1170
12.0	1295

TEST WITH 6-ft ICS - 5 PIERS



TEST WITH 6-ft ICS - 5 PIERS



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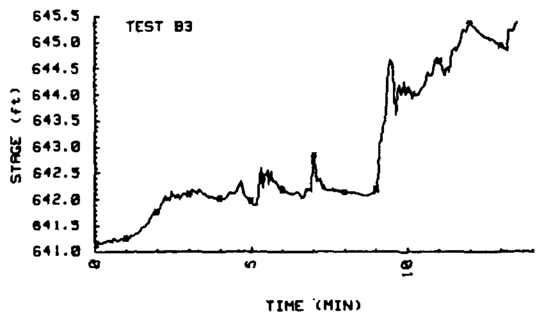

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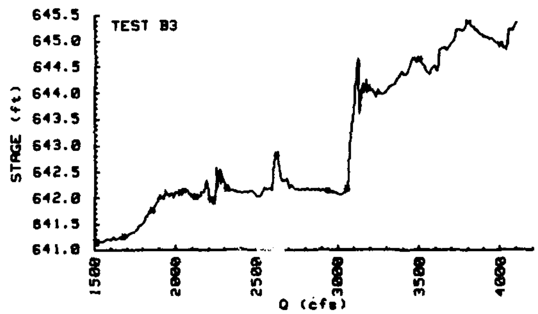

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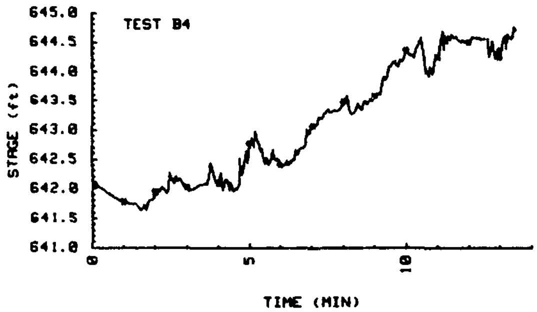

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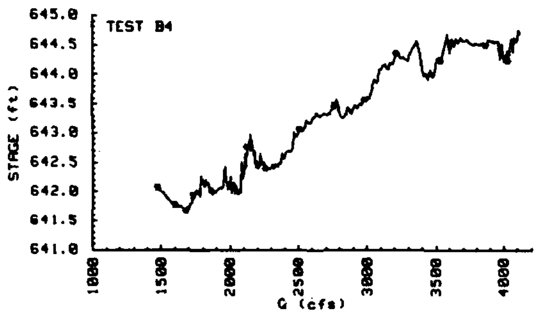

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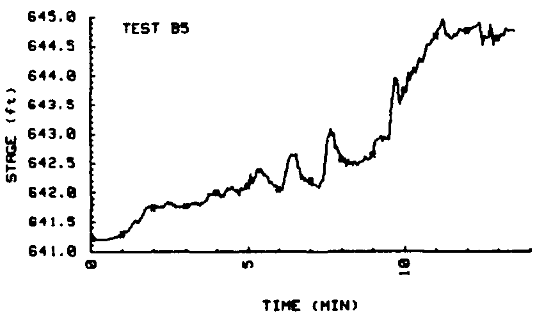

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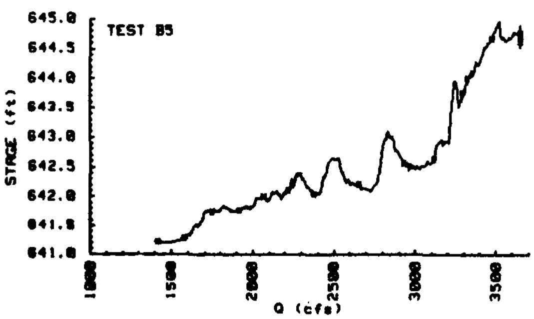
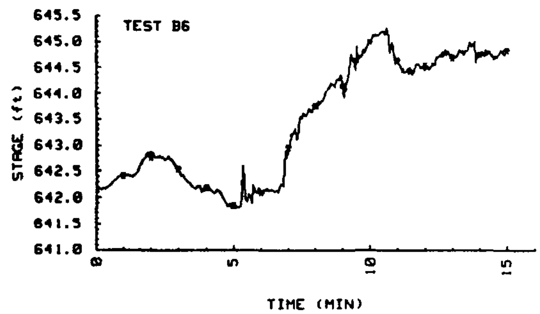


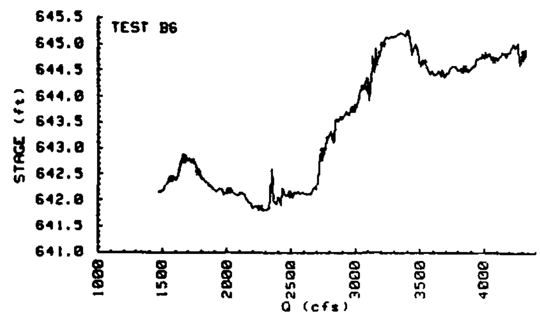
TEST SERIES WITH 6-FT ICS - 9 PIERS

TIME (MIN)	Q (GPM)
TEST # B6	
0.0	520
3.0	630
6.0	890
8.0	1060
10.0	1140
12.0	1365
14.0	1530

TEST WITH 6-ft ICS - 9 PIERS

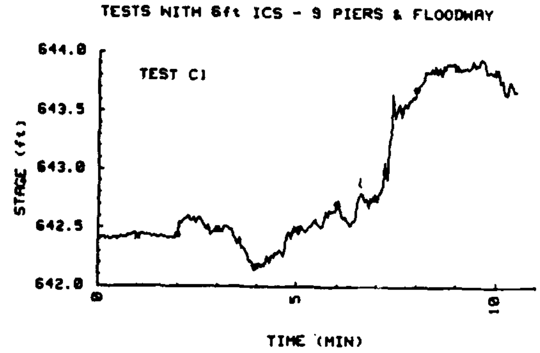


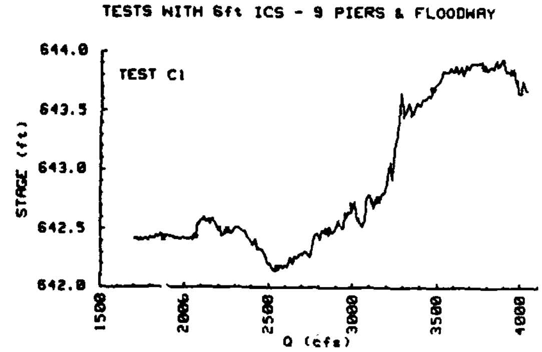
TEST WITH 6-ft ICS - 9 PIERS

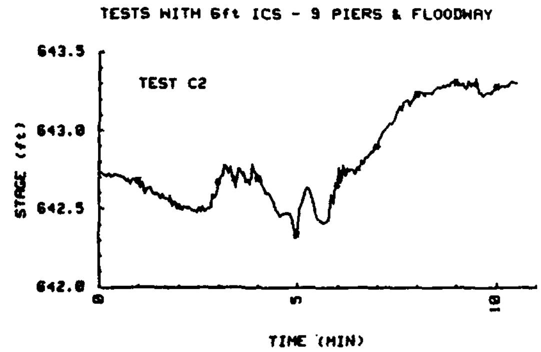


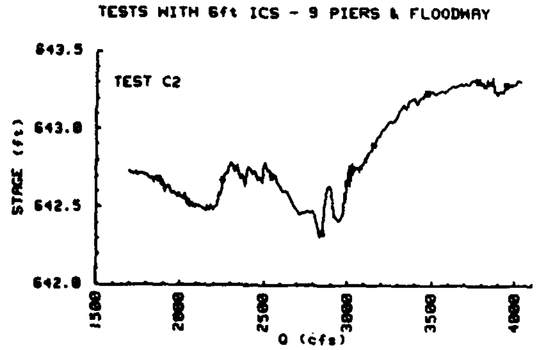
TEST SERIES WITH 6-FT ICS - 9 PIERS with FLOODWAY

TIME (MIN)	Q (GPM)
TEST # C1	
0.0	600
3.0	800
5.0	1010
7.0	1120
9.0	1340
11.0	1460
13.0	N.A.
14.0	N.A.
15.0	N.A.
TEST # C2	
0.0	600
3.0	800
5.0	1010
7.0	1120
9.0	1340
11.0	1460
TEST # C3	
0.0	650
3.0	780
5.0	1060
7.0	1150
9.0	1320
TEST # C4	
0.0	650
3.0	800
4.5	1100
6.5	1240
8.5	1400
10.0	1500
11.5	1700
13.0	2000

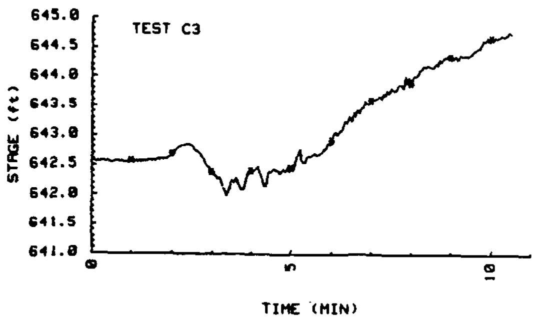




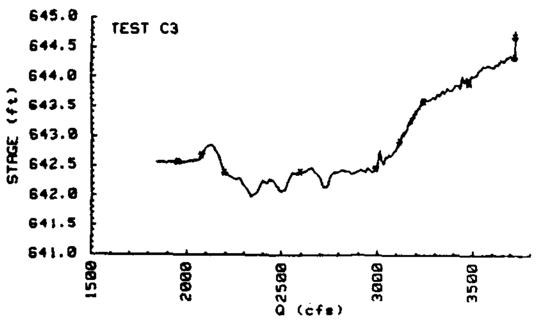




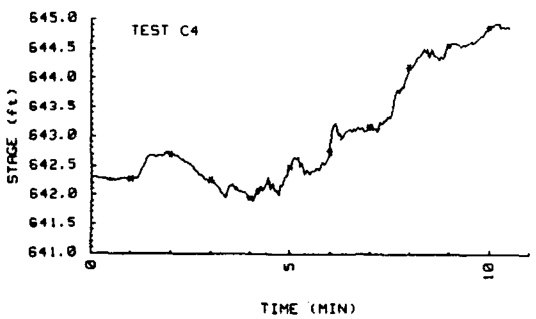
TESTS WITH 6ft ICS - 9 PIERS & FLOODWAY



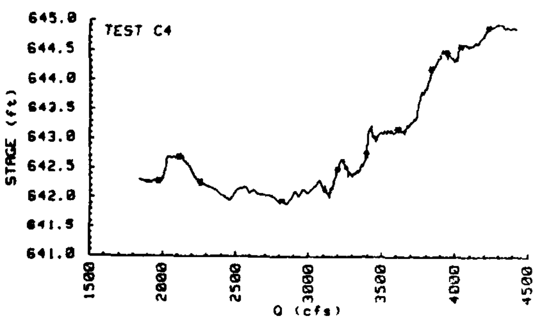
TESTS WITH 6ft ICS - 9 PIERS & FLOODWAY



TESTS WITH 6ft ICS - 9 PIERS & FLOODWAY



TESTS WITH 6ft ICS - 9 PIERS & FLOODWAY



REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
August 1990

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Model Study of the Cazenovia Creek Ice Control Structure

5. FUNDING NUMBERS
NCB-1A-83-87RC

6. AUTHORS
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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72 Lyme Road
Hanover, New Hampshire 03755-1290

8. PERFORMING ORGANIZATION REPORT NUMBER
Special Report 90-29

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer District
Buffalo, NY

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. *DISTRIBUTION CODE*

13. ABSTRACT (*Maximum 200 words*)
An ice control structure was chosen as a solution to ice-jam flooding of the business and residental communities of West Seneca and Buffalo, New York, along Cazenovia Creek. A model study was proposed to evaluate its performance before actual construction. This report describes the design, execution, and results of the model study, which led to the eventual acceptance of the proposed ICS by the U.S. Army Engineer District, Buffalo.

14. SUBJECT TERMS
Flood control   Ice jams
Ice control   Ice prevention

15. NUMBER OF PAGES
37

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

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298-102